CLAIMS

What is claimed is:

1. A cryogenic refrigeration system comprising:

an expansion nozzle having a high-pressure nozzle inlet and a low-pressure nozzle outlet;

an expansion volume in gaseous communication with the nozzle outlet; and

a compressor comprising

a reciprocating compression device operable to compress gas within a compression volume, wherein the compression volume has an inlet port and an outlet port,

a flapper inlet valve having

an inlet valve inlet, and

an inlet valve outlet in gaseous communication with the inlet port of the compression volume, wherein the inlet valve opens when a gaseous pressure at the inlet valve inlet is sufficiently greater than a gaseous pressure in the compression volume to overcome a spring force of the flapper inlet valve, and

a flapper outlet valve having

an outlet valve inlet in gaseous communication with the outlet port of the compression volume, and

an outlet valve outlet in gaseous communication with the nozzle inlet, wherein the outlet valve opens when a gaseous pressure in the compression volume is greater than a gaseous pressure at the outlet valve outlet to overcome a spring force of the flapper outlet valve; and

a drive motor system in driving mechanical communication with the compression device, wherein the compression volume is hermetically isolated from the drive motor system.

2. The cryogenic refrigeration system of claim 1, wherein a void volume of the flapper inlet valve and a void volume of the flapper outlet valve are

sufficiently small, in combination with a swept volume of the compression volume, that the compressor achieves a compression ratio of at least 15:1 in a single-stage of compression.

3. The cryogenic refrigeration system of claim 1, wherein the inlet valve inlet is in gaseous communication with the nozzle outlet.

4. The cryogenic refrigeration system of claim 1, further including a heat exchanger, wherein the outlet valve outlet is in gaseous communication with the nozzle inlet through a first channel of the heat exchanger, and the nozzle outlet is in gaseous communication with the inlet valve inlet through a second channel of the heat exchanger.

5. The cryogenic refrigeration system of claim 1, wherein the compression device comprises a piston suspended by a flexure.

6. The cryogenic refrigeration system of claim 1, wherein the compressor and the drive motor system are contained within a single hermetically sealed compressor housing.

7. The cryogenic refrigerator of claim 1, wherein the compression device comprises a pair of opposing compression pistons.

8. The cryogenic refrigeration system of claim 7, wherein the drive motor system comprises a linear drive motor having
a respective motor coil affixed to each one of the compression pistons, and
a respective magnet structure that is static.

9. The cryogenic refrigeration system of claim 7, wherein the drive motor system comprises a linear variable differential transformer providing a measurement of a position of each of the compression pistons.

10. The cryogenic refrigeration system of claim 1, wherein neither the inlet valve nor the outlet valve includes a compression spring that preloads a flapper seal.

11. The cryogenic refrigeration system of claim 1, wherein at least one of the inlet valve and the outlet valve includes a compression spring that preloads a flapper seal.

12. The cryogenic refrigeration system of claim 1, further including a cooled article in thermal communication with the expansion volume.

13. A cryogenic refrigeration system comprising:

a Joule-Thomson expansion nozzle having a high-pressure nozzle inlet and a low-pressure nozzle outlet;

an expansion volume in gaseous communication with the nozzle outlet; and

a compressor comprising

a pair of opposing flexure-suspended compression pistons operable to compress gas within a compression volume, wherein the compression volume has an inlet port and an outlet port,

a flapper inlet valve having

an inlet valve inlet, and

an inlet valve outlet in gaseous communication with the inlet port of the compression volume, wherein the inlet valve opens when a gaseous pressure at the inlet valve inlet is sufficiently greater than a gaseous pressure in the compression volume to overcome a spring force of the flapper inlet valve, and

a flapper outlet valve having

an outlet valve inlet in gaseous communication with the outlet port of the compression volume, and

an outlet valve outlet in gaseous communication with the nozzle inlet, wherein the outlet valve opens when a gaseous pressure in the compression volume is greater than a gaseous pressure at the outlet valve outlet

to overcome a spring force of the flapper outlet valve; and

a drive motor system in driving mechanical communication with the compression pistons, wherein the compression volume is hermetically isolated from the drive motor system, and wherein the compressor and the drive motor system are contained within a single hermetically sealed compressor housing; and

a heat exchanger, wherein the outlet valve outlet is in gaseous communication with the nozzle inlet through a first channel of the heat exchanger, and the nozzle outlet is in gaseous communication with the inlet valve inlet through a second channel of the heat exchanger.

14. The cryogenic refrigeration system of claim 13, wherein a void volume of the inlet valve and a void volume of the outlet valve are sufficiently small, in combination with a volume of the compression volume, that the compressor achieves a compression ratio of at least 15:1 in a single-stage of compression.

15. The cryogenic refrigeration system of claim 13, wherein the drive motor system comprises a linear drive motor having

a respective motor coil affixed to each one of the compression pistons, and

a respective magnet structure that is static.

16. The cryogenic refrigeration system of claim 13, wherein the drive motor system comprises a hermetically isolated linear variable differential transformer providing a measurement of a position of one of the compression pistons.

17. The cryogenic refrigeration system of claim 13, wherein each of the inlet valve and the outlet valve includes a compression spring that preloads a flapper seal.

18. The cryogenic refrigeration system of claim 13, further including a cooled article in thermal communication with the expansion volume.